MINIMUM TEMPERATURES IN THE LOWER STRATOSPHERE

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ABSTRACT

An analysis of the lowest temperatures observed at the base of the stratosphere in various zones of the globe shows that the recent records obtained over the Antarctic lower the previous world record of long standing, which was registered in the equatorial zone at Batavia in 1913.

1. INTRODUCTION

The thermal regime of the stratosphere is now the object of a thorough investigation. The steady flow of new temperature data obtained in the upper troposphere and lower stratosphere under the International Geophysical Year program enhances our knowledge, but also raises new problems in our understanding of the global stratosphere. The new data need critical evaluation. This, in turn, calls for a survey and for an analysis of the earlier records, to serve as a basis for comparisons with the later ones.

In this article, the lowest observed temperatures of the lower stratosphere are surveyed and analyzed on the global scale, to provide a background for further investigations in this field.

2. BATAVIAN RECORD

The first record low temperature in the lower stratosphere was registered by a sounding balloon over Batavia (Java) on November 5, 1913. It was −91.9° C. (−133.4° F.) at a height of 17,330 m.

Until 1958 this represented the lowest limit of temperature for the base of the stratosphere. Although in this ascent the clockwork had stopped, the register was accepted by W. van Bemmelen [3,4] who published it, without any reservation. A complete record of the first sounding, as van Bemmelen [3] gave it, is reproduced in table 1.

TABLE 1.—*Registering balloon ascent, Batavia, November 5, 1913*

Local time (hr.)	Local time (min.)	Altitude (m.)	Pressure (mm.)	Temperature (°C.)	Remarks
4	25	8	750	23.6	
				25.7	Clock stops. Inversion.
	0.00	3,950	477	3.3	Clock starts again.
		4,000			
	1.43	4,320	456	2.1	
		4,500			
	2.78	4,770	431	−0.9	
		5,000			
	5.50	5,440	396	−6.0	
		5,500			
		17,330	65	−91.9	Maximum height, minimum temperature.
		10,720	198	−43.0	
		8,740	258	−28.0	
		6,160	364	−9.1	
		25	760	27.1	

Since this record represents a rather isolated reading, its authenticity would be questionable if it were not supported by another, very detailed and high-reaching sounding, made at the same location a month later. The second sounding during which very low temperatures were recorded at Batavia was conducted on December 4, 1913. The registering balloon reached 26,040 m. and the readings are to be depended upon. The lowest temperatures registered during this ascent were: −89.5° C (−129.1° F.) at 17,000 m. on the way up, and −99.9° C. (−131.6° F.) at 16,500 m. on the way down. There is a very complete tabular record of this sounding [3] which is reproduced here in graphic form in figure 1.

To complete the discussion of the Batavian world record of lowest temperature at the base of the stratosphere, it should be mentioned that only one case of a competing value (before the recent Antarctic records) was found in meteorological publications. This however, as we shall show, is disqualified by proper analysis of the sounding. A. Wagner [24] mentioned that a minimum temperature of the upper air of −92° C. was registered in Agra (India) (27°10′ N., 78°05′ E.), which was equal to that recorded over Batavia. Wagner derived this information from G. Chatterjee and N. K. Sur [5], who, in turn, had reproduced a graph from K. R. Ramanathan [17]. In reproducing it they made an error, showing one dot too many and in a wrong place. It was this dot that showed the extremely low temperature of −92° C., which had neither been shown nor discussed in the original publication of the Agra upper-air temperatures by Ramanathan

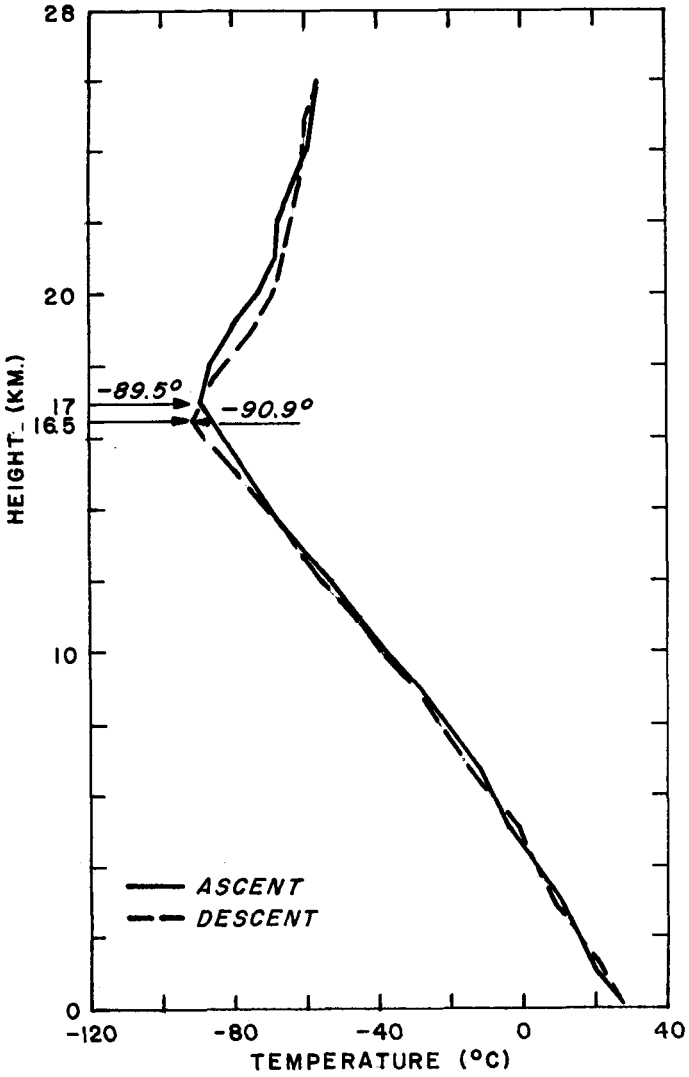

FIGURE 1.—Upper-air sounding at Batavia, Java, December 4, 1913.

[16]. Also incorrect in the same source [5] is the year of the Batavian records, which are ascribed to December 5 and November 4, 1923. These records were registered in the year 1913, as the original paper by van Bemmelen [3] indicates.

3. LATER LOW-LATITUDE DATA

It is remarkable that since the time of the famous Batavian record in 1913 no lower temperatures were observed in the stratosphere until recently. To illustrate the usual values of the lowest temperatures obtained in the atmosphere over the low latitudes, data extracted from [20] for three stations in the Caribbean region are given in table 2. These data indicate, however, that temperatures close to the Batavian records probably could be obtained in this region if the soundings extended just one kilometer higher; i.e., reaching the levels of the Batavian records, which were registered at 17,000 and 16,500 meters.

TABLE 2.—*Lowest temperatures (°C.) by height for three stations in Caribbean region (from [20])*

Height (km.)	San Juan, P.R., 1941–45	Swan Island, 1940–45	Tacubaya, Mexico, 1943–45
Surface	17	18	4
1	13	12	----
2	7	6	----
3	2	3	3
4	−3	−3	−2
5	−9	−9	−9
6	−15	−17	−15
7	−22	−20	−22
8	−29	−27	−28
9	−36	−35	−37
10	−46	−43	−46
11	−55	−51	−54
12	−62	−59	−63
13	−69	−68	−70
14	−75	−76	−75
15	−82	−82	−79
16	−88	−87	−85

D. Dewar [7], in his recent brief communication, has mentioned an isolated value of −97°C. recorded at 100 mb. in Verval (India), and −94°C. at the same level in Columbia (Ceylon) during 1944–50.

Observations on minimum temperatures of the tropopause in Bangui, French Africa (4°22′ N., 18°34′ E.; H=386 m.) during the period 1953–57, as given in a recent publication [12], showed the following lowest temperatures by months:

	°C.		°C.
January	−83.9	July	−81.4
February	−85.6	August	−80.0
March	−88.0	September	−82.0
April	−85.8	October	−84.7
May	−86.4	November	−85.5
June	−81.5	December	−84.4

The absolute minimum was observed in March, but the publication does not say at what altitude this temperature was registered.

4. MIDDLE-LATITUDE DATA

It is well known that in the middle latitudes the base of the stratosphere is warmer and temperatures there

TABLE 3.—*Lowest temperatures (°C.) by height for four stations in the middle latitudes (from [20]). The lowest minima are underscored*

Height (km.)	El Paso, Tex. (31°48′N.), 1939–45	Albuquerque, N. Mex. (35°05′N.), 1943–45	Denver, Colo. (39°45′N.), 1939–45	Rapid City, S. Dak. (44°02′N.), 1943–45	Glasgow, Mont. (48°11′N.), 1943–45
Surface	−17	−27	−34	−37	−57
1	----	----	----	−24	−26
2	−11	−12	−22	−24	−25
3	−13	−17	−26	−26	−28
4	−19	−23	−33	−33	−34
5	−26	−30	−37	−40	−41
6	−33	−38	−41	−45	−46
7	−41	−46	−49	−52	−54
8	−49	−50	−53	−55	−61
9	−53	−55	−58	−59	−62
10	−57	−60	−65	−64	−63
11	−64	−65	−68	−66	−67
12	−68	−69	−72	−70	−71
13	−72	−70	−71	−71	−72
14	−79	−71	−72	−68	−71
15	−77	−76	−73	−70	−72
16	−80	−77	−76	−70	−66

cannot compare with the records from the equatorial or tropical zone. Table 3 gives data for several stations in the United States, approximately along the 105th meridian, listed in the order of increasing latitude. More recently a temperature of −80° C. at 33 mb. was recorded at Salem, Oreg., on February 4, 1957 [22].

5. HIGH-LATITUDE DATA

ALASKA

The pattern of the vertical distribution of the lowest temperatures over Alaska is shown in figure 2a (from [20]). The lowest temperatures obtained by radiosoundings are: In Fairbanks −72° C. (−97.6° F.), 1939–45, at 11 km.; in Nome −69° C. (−92.2° F.), 1940–42, at 12 km.; in Barrow −74° C. (−101.2° F.), 1940–45, at 11 km. For comparison, data for two low-latitude stations (from [20]) are also displayed in figure 2b.

GREENLAND

The latest published data for Greenland come from the expedition led by Paul-Emile Victor from September 1949 to August 1951. During this period 192 soundings were made at the French station (70°55′ N., 40°38′ W.; H=2993 m.). The lowest temperature was recorded at approximately the 150-mb. surface on March 11, 1950, at 3 p.m. It was −74° C. (−101.2° F.). This ascent (from [1]) is shown in figure 3.

Wexler and Moreland [25] mention "stratospheric temperatures found at Thule, Greenland, in late January 1952 . . . as low as −81° C".

ARCTIC REGIONS

Radiosoundings made from the Soviet ice floe station "North Pole–4" during the period from April 1955 to April 1956 obtained, for the first time, more or less complete data on air temperatures aloft over the Central Arctic region [11]. The ascents reached up to 35,540 m.

In October and December the temperature in the lower stratosphere usually decreased with height, whereas the troposphere was still of an inversional or isothermal type. After November 30, a decrease in temperature with height was observed in the troposphere also. Thus, for the midwinter, a troposphere with a slightly falling temperature, and a more rapid fall of temperature in the lower stratosphere, was typical.

In December 1955, at an altitude of 18.5 km., a temperature as low as −77.4° C. (−107.3° F.) was recorded for the first time. It was observed in a high-level cyclone which had its center over Baffin Bay. In the upper troposphere, at heights of 10–11 km., strong westerlies of more than 75 m./sec. indicated the existence of great thermal contrasts and pressure gradients, as effected by an intensely cold air mass. On December 6 and 7, temperatures of −78° C. (−108.4° F.) and −79° C. (−110.2° F.) were recorded in the lower stratosphere, and on January 4, 1956, the lowest temperature on record for this region was observed, −81.2° C. (−114.2° F.). It was registered at an altitude of about 20 km. At that time the drifting station was in the region of 85° N., 179° E. This ascent is reproduced from the source [11] in figure 4. The atmospheric processes in 1955–56 were rather abnormal, especially so in the midwinter when an extremely strong cyclonic activity developed; this could be one of the causes for a colder stratosphere.

The records of lowest temperatures obtained by earlier drifts in 1953–55 by "North Pole-3" and "North Pole-4" gave −70.2° C. (−94.4° F.) at 8.9 km. on December 21,

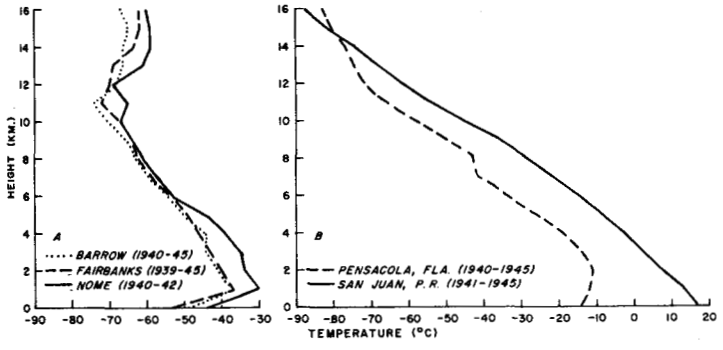

FIGURE 2.—Vertical distribution of lowest temperatures at (a) three Alaskan stations, and (b) two low-latitude stations.

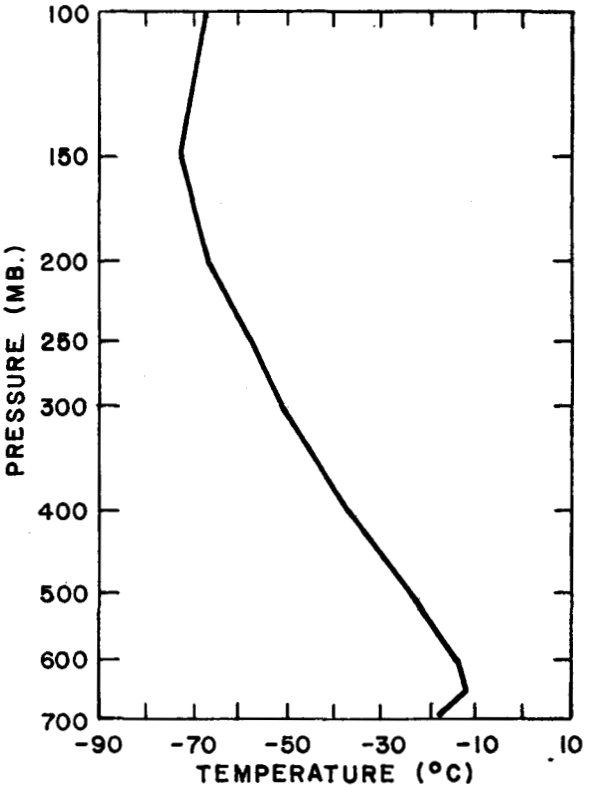

FIGURE 3.—Upper-air sounding at French station in Greenland, March 11, 1950 (from [1]).

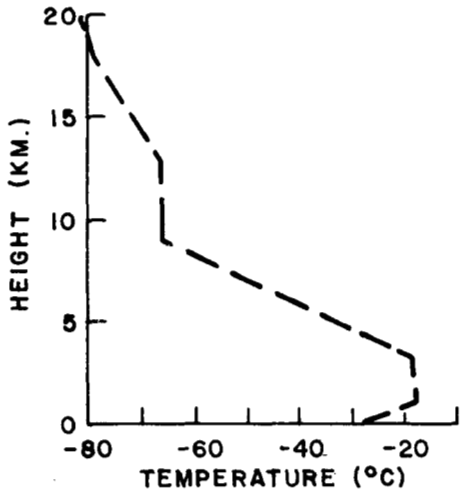

FIGURE 4.—Upper-air sounding at drifting station "North Pole-4" (85° N., 179° E.), January 4, 1956.

1954 and −71.6° C. (−96.9° F.) at 9.5 km. on November 13, 1954, respectively. At those times the soundings were limited to 12–14 km.

Belmont [2] gives the following data on minimum temperatures of the stratosphere as recorded from the Ice Island T–3. This island was floating in the Central Arctic during the period June 20, 1952–March 4, 1953. The absolute minimum temperatures derived from minimum curves are as follows:

	°C.		°C.
June 1952	(−58)	November 1952	−57
July	−57	December	−63
August	−58	January 1953	−68
September	−62	February	−59
October	(−62)	March	(−62)

The parentheses show values based on less than 10 days data. The author indicates that in this region ". . . the apparent mean tropopause height is near 300 mb. from June to October, and then it lowers to about 370 mb. in November and it may be interpreted as lying between 350 and 370 mb. from December to March. The level of minimum temperature generally occurs about 25 or 50 mb. higher than the level of significant decrease in lapse rate at which we define our tropopause."

In [22] the following minimum stratospheric temperatures are reported for the Arctic for the year 1957:

Temperature	*Station*	*Height*	*Date*
−81° C.	Ice Skate "A"	19.6 km. (45 mb.)	Dec. 21
−82	Eureka	25 mb.	Dec. 11, 26, 30
−81	Alert, N.W.T.	30 and 40 mb.	Jan. 23
−80	Mould Bay	40 mb.	Jan. 29

A temperature of −83° C. was recorded by Bjerknes (1939) in As, 60 km. south of Oslo, at 23.5 geodynamical km. as published by H. Dieterichs [8].

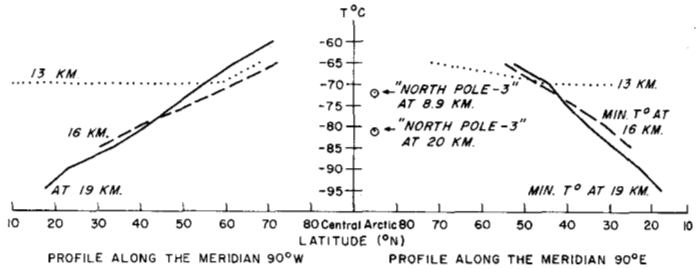

FIGURE 5.—Profiles of minimum temperatures at three levels in the Northern Hemisphere.

6. NORTHERN HEMISPHERE

To consolidate the knowledge of the lowest temperatures in the upper layer over the Northern Hemisphere the distribution of the lowest temperatures observed at the levels of 13, 16, and 19 km. is presented on a profile graph along the 90th meridian in figure 5. This graph is based on data given in [21] and on observations made by drifting stations "North Pole-3" and "North Pole-4". Figure 5 affords a general view of the variations of the lowest temperatures with latitude at three altitude levels. Since the maps of [21] present some interpolated values which have never been observed but only theoretically computed, especially for the 19-km. level, so does the graph.

7. ANTARCTICA

Paradoxical as it may seem, it was over the Antarctic continent that the temperatures competing with the Batavian world record were registered, for the first time at Maudheim (−91° C.) in the winter of 1950 [18], and later at Amundsen-Scott (South Pole) station (−91.2° C.) in the winter of 1957 [10].

The records of radiosoundings in Antarctica have frequently indicated the fact that, in the midwinter season, the temperature diminished with height continuously throughout the troposphere and in the lower stratosphere as well. The tropopause was frequently missing. This has led to the conclusion that, in the middle of the winter season, the tropopause in the Antarctic actually disappears. Such a statement was first made by Court [6], and later it was confirmed by Rusin (see [14]), the aerologist at Mirny. A continuously decreasing temperature, up to 16 or 17 km., reaching −75° and −76° C. was recorded over Mirny and Pionerskaya, as reported by Laktionov [14], who also claimed that at the height of 18–20 km. over Mirny, a distinctive westerly jet stream of 100 m./sec. was observed.

According to recent publications the first new world record of the lowest temperature in the lower stratosphere that broke the Batavian record was −93.0° C. (−135.4° F.) at 21 km. at Amundsen-Scott (South Pole) station, 0000 GMT, July 17, 1958, as reported by the U. S. National Academy of Sciences [15].

TABLE 4.—*Radiosonde ascents which recorded the lowest temperatures in the upper layers in 1958 in Antarctica*

Pressure (mb.)	Amundsen-Scott (South Pole) (90° S., H=2800 m.), July 17, 0000 GMT	Byrd (79°59′ S., 120°01′ W.; H=1515 m.), July 15, 1200 GMT	D'Urville (66°40′ S., 140°01′ E.; H=40 m.), July 28, 0000 GMT	Hallett (72°18′ S., 170°18′ E.; H=5 m.), Sept. 4, 1200 GMT	Little America (78°11′ S., 162°10′ W.; H=45 m.), July 10, 1200 GMT	McMurdo (77°51′ S., 166°37′ E.; H=45 m.), Aug. 28, 0000 GMT	Mirny (66°16′ S., 110°31′ E.; H=30 m.), July 20, 1200 GMT	Sovetskaia (70°24′ S., 87°35′ E.; H=3570 m.), Aug. 8, 0000 GMT	Wilkes (66°35′ S., 110°31′ E.; H=12 m.), Aug. 28, 0000 GMT
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
24					−91				
25	−93	−92							
27					−91				
30	−93								
32									−81
37						−87			
44				−84					
45								−91	
47	−89		−73						
50	−91	−89	−72	−84	−89	−85		−91	−78
65							−84		
100	−83	−83	−68	−76	−80	−81	−72	−86	−73
150	−76	−77	−66	−72	−75	−75	−68	−78	−66
200	−72	−75	−66	−68	−73	−73	−65	−76	−60
300	−65	−67	−61	−60	−65	−66	−58	−70	−52
400	−53	−51	−52	−49	−54	−56	−49	−62	−45
500	−43	−37	−44	−39	−43	−44	−41	−54	−41
550								−54	
575								−60	
591								−80	
597	−37								
640	−40								
666	−53								
700		−22	−25	−25	−26	−30	−28		−23
800				−33	−21	−33			
850							−20		−13
900				−31					
940									−9
980					−29	−29	−22		
995					−39	−29	−22		
1,000					−39				−12

The record of this radiosounding is reproduced in table 4 which shows also the records of other radiosoundings which registered the lowest temperatures in the upper layer at their respective stations in 1958. This table was compiled from the abundant aerological data collected and worked up by the Polar Meteorological Research Unit, U.S. Weather Bureau, which were made available to the author by the kind cooperation of the Chief of this Unit, Mr. M. J. Rubin, and his assistant, Mr. E. C. Flowers.

With the arrival of reports of the radiosoundings made on Falkland Islands [9] it became obvious that the lowest temperatures in the lower stratospheric layers had been registered by the Halley Bay station. In table 5 several records of radiosoundings at this station are reproduced showing temperatures in the lower stratosphere as low as −94°, −95°, −101°, and even −109° C. It seems to us that the readings of −109° and −101° C., as recorded on the 12th and the 17th of July at Halley Bay, are somewhat too low and the respective lapse rates too large to be trusted without further verification, but the temperature of −94° C., as observed on July 3, 11, and 27, and even the temperature of −95° C. observed on July 6, 1958 at the 18-mb. level seem to be reliable enough to be taken into consideration.

TABLE 5.—*Radiosonde ascents at Halley Bay, 75°31′ S., 26°36′ W., H=30 m., July 1958*

July 3 1200 GMT		July 6 1200 GMT		July 7 1200 GMT		July 11 1200 GMT		July 12 1200 GMT		July 17 0000 GMT		July 27 1200 GMT	
mb.	*° C.*	*mb.*	*° C.*	*mb.*	*° C.*	*mb.*	*° C.*	*mb.*	*° C.*	*mb.*	*° C.*	*mb.*	*° C.*
25	−94	18	−95	20	−93	20	−94	23	−109	28	−101	30	−93
37	−91	61	−90	26	−93	35	−90	35	−91	35	−93	52	−94
77	−85	111	−81	40	−88	45	−90	40	−87	44	−90	62	−91
242	−70	117	−79	50	−89	56	−86	67	−86	90	−84	72	−93
332	−60	164	−80	98	−80	68	−85	76	−84	118	−80	100	−86
420	−50	179	−78	149	−73	168	−75	85	−84	294	−79	104	−87
509	−40	608	−27	255	−68	190	−72	108	−79	407	−49	110	−85
604	−33	804	−15	315	−60	242	−73	125	−79	464	−44	135	−87
672	−28	999	−33	802	−16	282	−69	165	−73	648	−30	148	−85
827	−22			983	−23	312	−71	196	−76	760	−27	181	−85
1006	−32					661	−34	279	−68	840	−23	288	−60
						987	−46	295	−67	990	−16	400	−44
								625	−34			637	−23
								730	−28			988	−24
								894	−21				
								984	−28				

8. CONCLUDING REMARKS

Comparing the minimum temperatures in the lower stratosphere as recorded by several stations, and analyzing their reliability, one should consider the order of magnitude of those differences in temperature which are observed between individual radiosondes of various countries under equal conditions. Results of the comparison of temperature readings obtained by individual simultaneous soundings have been reported by Harmantas [13]. Using the data of simultaneous soundings made in Payerne, Switzerland, in May-June 1956, Harmantas compared the records of temperature obtained by radiosondes of 13 countries with those of the United States. It has been found that at surfaces higher than the 30-mb. level serious radiation errors exist. At night, the differences in temperature at the 50-mb. level varied within limits of −2° and +1.9° C., while the daytime soundings showed a much wider range of differences, limited by −18.1° and +5.6° C. Teweles and Finger [19] recently derived an empirical system for the reduction of diurnal variations in the reported temperatures and heights of stratospheric constant pressure surfaces from soundings made during the IGY.

At the present time it is not possible to ascertain that any one of the above-mentioned temperatures is the new world record of the lowest temperature for the lower stratosphere, and all that this article attempts to do is to provide a summary of the available data on this subject to facilitate future research.

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